V. *On Intensity Relations in the Spectrum of Helium.*

By T. R. MERTON, *D.Sc., Lecturer in Spectroscopy, University of London, King's College, and* J. W. NICHOLSON, *F.R.S., Professor of Mathematics in the University of London.*

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(I.) *Introductory.*

THE two most fundamental characteristics of a spectrum line are its wave-length and its intensity, and it is very remarkable that, at the present time, while the former can often be expressed with an accuracy of one part in half a million, the tabulated intensity may frequently be affected by an error even greater than a thousand per cent. Yet for the elucidation of the main problems of astrophysics the relative intensities of spectrum lines may assume an importance scarcely inferior to that of a precise knowledge of their wave-lengths. Although data of the latter kind afford precise evidence of the presence of certain elements, and of the motions of stars and nebulæ in the line of sight, it is to the distribution of energy in the spectrum and to the reproduction of specified conditions in the laboratory that we must look for a further knowledge of the physical and more especially the electrical conditions obtaining in celestial bodies.

The changes which occur in spectra under varying conditions of excitation are often of a very conspicuous character, and the study of "spark" or enhanced lines

has already led to results of fundamental importance, but the observation of such phenomena depends for its success upon the magnitude of the changes involved, and whereas the appearance of new series of lines under appropriate conditions is often apparent at once, a strictly quantitative determination of the relative intensities of the spectrum lines is necessary for the study of the less conspicuous changes, which may, nevertheless, be of fundamental importance. In particular, the intensity changes occurring under varying conditions in lines belonging to the same or to mathematically related series must be a matter for serious consideration in any theory of radiation which involves a theoretical interpretation of the laws of spectra.

In a recent investigation* we have made quantitative measurements of the intensities of the lines of Helium and Hydrogen, and it was found that under certain conditions of energetic excitation, the relative intensities of the lines were altered, in the sense that there was a transfer of energy from the lower to the higher members of the various series. This phenomenon was found to occur under appropriate circumstances in every series investigated, although the absolute magnitude of the change or transfer is peculiar in each case to the individual series. The principal difficulty encountered in any attempt to obtain an interpretation of such results lies in the absence of any precise knowledge of the conditions of excitation which actually obtain with any specified experimental arrangement. The three cases which we investigated in connection with Helium were the spectrum, from the capillary of a vacuum tube of the Plücker form, produced by the passage of an uncondensed discharge from an induction coil, and alternatively by a condensed discharge with a spark gap in the circuit, together with the spectrum from the bulb produced with a condenser in parallel and with a very small spark gap; but in each of these cases, our knowledge of the manner in which the atom is excited to luminosity is not sufficiently definite to justify any attempt to correlate theoretically the observed intensity changes.

The variations in the intensity distribution among the lines of a spectrum, produced by the presence of impurities or by the direct admixture of other gases, constitute another field for research, and in this connexion a large number of entirely distinct effects may occur. Quite apart from the emission of band spectra by definite compounds or perhaps elementary molecules, and of such spectra as the water-vapour bands and the ammonia bands, which have been shown recently† by FOWLER to be present in the solar spectrum, there exist such effects as the reduction of intensity of the band spectrum of Helium, produced by the action of certain impurities, and the similar action of Oxygen on the secondary spectrum of Hydrogen. We have also confirmed, in a quantitative sense, the original observation of LIVEING and DEWAR that a transfer of energy from longer to shorter wave-length in the Balmer

* 'Phil. Trans.,' A, 1917, vol. 217 p. 237.

† 'Roy. Soc. Proc.,' A, 1918.

series of Hydrogen is brought about by the admixture of Neon. The importance of the mutual effects of gases on the intensity distribution in their spectra is considerably enhanced by the fact that, in celestial spectra, the radiation from a pure gas is never in question, and if indeed the spectrum of any single element were manifest, its presence would not disprove the presence of other elements which, though not giving rise to perceptible radiations peculiar to themselves, might nevertheless exert an influence on the distribution of intensity in lines due to other elements.

A third and most significant condition which affects the relative intensities of spectrum lines is the pressure of the gas from which they are produced. In Helium, as is well known, this is peculiarly conspicuous; the colour of the discharge, for example, being green at low pressures. The existence of this phenomenon has, in fact, been familiar for many years, and indeed was responsible at one time for the erroneous view that Helium was a mixture of two gases. This misconception was only removed by the demonstration that the effect in question was due to variations of the pressure of the gas in the tube, but there has since been no quantitative investigation of the nature of the changes which are known to occur.

It is thus evident that there are a number of circumstances which modify the distribution of intensity in the spectrum of an element, and that in order to obtain further information it is desirable to investigate the simplest possible cases in which the nature of any changes introduced into the method of excitation of the spectrum can be followed in some detail. Such considerations have been the determining factor in the particular conditions which have been selected for study in the work described in the present communication.

(II.) *The Cathode Glow.*

A source of light in which we already have some definite information with regard to the electrical conditions is obviously presented by the glow around the cathode of a vacuum tube. The radiations obtained from this source in the case of Helium are of especial interest, for they include at once the "arc" lines, the spark line at "4686," and also the band spectrum which FOWLER has shown recently* to be of an unusual type, inasmuch as the heads of the bands are not related by the law of Deslandres appropriate for the usual band spectra, but by the Rydberg formula which had been regarded hitherto as applying exclusively to line series. The presence of the "4686" line in the same source is also interesting, as the appearance of a characteristic "spark" line in company with a band spectrum is perhaps somewhat surprising, although the existence of such a phenomenon shows clearly that, though the conditions necessary for the production of these radiations may be different, they are evidently at the same time not incompatible.

* 'Roy. Soc. Proc.,' A, vol. **91**, p. 208, 1915.

In recent years the radiation from the dark space has become of particular interest in view of the fact that it is in this region that the Stark effect—or the electrical resolution of spectrum lines analogous to the magnetic resolution known as the Zeeman effect—is observed.

In this region the quantitative relation between the electric field and the distance from the cathode was first investigated by SCHUSTER,* who expressed his results by the empirical formula

$$V = V_0(1-e^{-kx}),$$

where the potential of the cathode is taken as zero and V_0 is the potential of the cathode glow, V is the potential at distance x from the cathode and k is a constant.

This formula gives the distribution of potential in the dark space, and more recently LO SURDO,† from a series of measurements of the electrical separation of spectrum lines in front of the cathode, has verified that it is a satisfactory first approximation. Investigations in this direction have also been carried out by ASTON‡ and by HARRIS,§ who measured the deflection of a beam of cathode rays passing in a direction perpendicular to the electric field.

We do not discuss these observations in detail. Very recently the distribution of potential in narrow tubes has been investigated somewhat exhaustively by TAKAMINE and YOSHIDA,‖ who found that, under the conditions of their experiments, the relation between the electric field and the distance from the cathode could be represented, within the limits of experimental error, by a parabolic law.

In the work described in the present communication, we are concerned with pressures somewhat greater than have been used by these investigators, and with the cathode glow itself in addition to the dark space, and although a knowledge of the precise distribution of potential, from the cathode to a distance at which there is no longer any perceptible luminosity, would be of value, it is not in the first instance essential to a discussion of our results. For this purpose we may, in fact, merely assume that the electric field falls away rapidly with increasing distance from the cathode without the necessity of postulating any exact law. For it would appear that the average velocities of the electrons at different distances from the cathode (in which the effect of collisions naturally plays an important part) are probably more strictly relevant to a discussion of the results. A visual examination through coloured glasses of the cathode spectrum of the tube used in this investigation at once shows that the term "dark space" is, in fact, a purely relative one, and refers only to the integrated effect on the eye of all the radiations emitted.

* 'Roy. Soc. Proc.,' vol. 47, p. 541, 1890.

† 'Rendiconti R. Accad. Lincei,' vol. 23, 117, 1914.

‡ 'Roy. Soc. Proc.,' vol. 84, p. 526, 1910.

§ 'Phil. Mag.,' vol. 30, 182, 1915.

‖ 'Mem. Kyoto Imp. Univ.,' vol. ii., 6, 1917.

(III.) *The Method of Measurement.*

The method adopted for the determination of the intensities of lines in a spectrum has been described in a previous communication,* in which it was shown that the absolute values of the intensities can be obtained from the "photographic" intensities by the adoption, as a standard, of the radiation from the positive crater of the carbon arc, in which the distribution of intensity along the spectrum can be calculated by PLANCK'S or WIEN'S formula. For the purpose of the present investigation, the photographic intensities afford all the necessary information, and the results exhibited below are accordingly limited to a determination of these values.

The spectrograph consisted of a large single prism constant-deviation instrument by Hilger, with a camera attachment in place of the telescope. Instead of the V-shaped slide for reducing the length of the slit, a brass slide with a rectangular opening was adopted, and in front of this opening was fixed the neutral glass wedge. This consisted of a prism of neutral-tinted glass cemented to a similar prism of colourless glass in such a manner that the combination formed a plane-parallel plate. When light is allowed to fall on to the slit through this wedge, the resulting spectrum is found to consist of lines which are bright at one end, corresponding to the thin end of the wedge, and which fade away in the direction corresponding to the dense end of the wedge, the length of the line on the plate thus depending on its intensity and also on the "density" of the wedge for that particular wave-length.

The spectra under investigation were photographed on Wratten Panchromatic plates, and these were developed with a Hydroquinone and Formaline developer which gives results showing great contrast. From the negatives thus obtained, positives were printed by contact on Paget Half-tone or Paget Slow Lantern plates, which were found to give the best results for this stage of the process. These positives were then intensified with Mercuric Chloride and Ammonia, and enlargements were subsequently made on bromide paper using a Zeiss "Tessar" lens, which, under the conditions of use, gave no measurable amount of distortion of the image. The enlargements were made with the aid of a ruled process screen, which was placed immediately in front of the bromide paper. The resulting enlarged negative image was in this way built up from a number of small dots, one-hundredth of an inch apart. On the enlargement obtained by this method, it is a matter of no difficulty to pick out the last dot visible on each line, and thus to determine with considerable accuracy the relative lengths of the lines composing the spectrum. In the absence of the process of reproduction of the image in dots, this would be a matter of great difficulty, and the results would be subject to considerable personal error.

The plate-holder of the spectrograph was provided with a rack and pinion motion in order to allow of the possibility of photographing a number of spectra on the same plate. The spectra under comparison are thus photographed on adjacent portions of

* *Loc. cit.*

the same plate, ensuring a valid basis for the comparison, and pass simultaneously through all the subsequent stages of the process.

It has been found most convenient to deduce the photographic intensities in the following manner, the theory of which has been given in some detail in a previous paper,* though circumstances have slightly modified the method in the present instance. We define the "density" of the wedge at any point as $-\log_{10}\left(\frac{I_1}{I_0}\right)$ where I_0 and I_1 are respectively the intensities of the incident and transmitted rays. This density is proportional to the length measured from the thin end, and the density at the thick end was denoted by D_λ in the former paper, the suffix λ relating to the particular wave-length in question. The photographic intensity of a line was proportional to the function

$$\log_{10}^{-1}\left(\frac{D_\lambda h_\lambda}{H}\right)$$

where h_λ and H were the heights of the line, and of the wedge, on the enlarged photograph. If h is the height of the wedge on the original plate, and m is the magnification,

$$H = mh.$$

Let $D_\lambda/h = d_\lambda$, the change of density of the wedge per millimetre or its density gradient. Then the photographic intensity of a line of wave-length λ is measured by

$$\log_{10}^{-1}\left(\frac{d_\lambda\, h_\lambda}{m}\right).$$

The height of the line on the enlargement is h_λ and on the original plate before magnification, is h_λ/m. The magnification m can be found at once if the interval between any two lines, such as $\lambda\lambda$ 6678 and 3888, is known both on the original plate and on the magnified photograph.

A precise knowledge of the values of d_λ at various typical points in the region of the spectrum under investigation is required or, in other words, the wedge must be calibrated. The wedge used in the present experiments was of somewhat more convenient dimensions than that employed in our previous investigation, and an improved method of calibrating it has been adopted.

For this purpose, a vacuum tube containing Helium was excited to luminosity by means of the induction coil with a mercury jet interrupter, and the capillary of the tube was brought to a focus of the slit of the spectrograph, with the wedge in position, by means of two convex lenses. The distance of the tube from the slit, and the positions of the lenses, were so adjusted that the distances between the capillary and the first lens, and between the second lens and the slit, were equal respectively

* *Loc. cit.*

to the focal lengths of the lenses. With this arrangement, an exposure was made for a definite time on the plate.

A perforated metal plate was then introduced between the two lenses, and another exposure for the same period of time was made on an adjacent portion of the same plate. This perforated plate consisted of a thin sheet of metal drilled with small holes at regular intervals of about a millimetre. By taking the mean of a number of micrometric determinations of the diameters of these holes and of the distances between them, the effective "density" of the metal plate could be calculated. The difference in the lengths of corresponding lines in the two spectra thus denotes the density step due to the plate, which is equal to the "density" of the perforated metal plate, from which the density step per millimetre length of wedge was calculated. The values thus found by the use of all the stronger Helium lines were plotted on squared paper against the wave-lengths, and a curve was drawn through these points. This curve was quite regular, and of the same type as that shown in the previous paper for another wedge, though obtained now by a different and in some respects better method. Actual values of the density gradient may be found in the tables given in later sections of this communication.

(IV.) *Experimental.*

In the present investigation we have examined the radiation in front of a flat aluminium cathode about 1 inch in diameter, which fitted closely into a cylindrical tube, as in fig. 1. The tubes were highly exhausted by means of a Gaede mercury

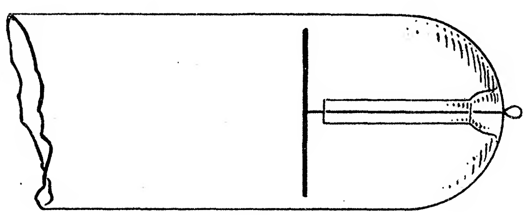


Fig. 1.

pump, and after continuous sparking, connection with the pump was cut off and Helium was introduced by heating a quantity of powdered Thorianite contained in a fused silica bulb, which was connected with the vacuum tubes through a tube containing pieces of caustic potash and a U-tube containing charcoal cooled with liquid air. After sparking for some time, the tubes were sealed off, and were found to contain, in addition to the Helium, a certain amount of Hydrogen and also of Mercury vapour. A great part of the latter disappeared on further sparking, and finally the Mercury spectrum settled down to a constant intensity. The pressure in the tubes was such that the thickness of the dark space was about 1 mm. With electrodes of these dimensions, the tubes could be run with a moderate current for an

almost indefinite period without any noticeable change, and there was no trace, on the walls of the tube, of any metallic deposit from the electrodes. We have, in addition, used tubes of the ordinary H pattern for the investigation of the mutual action of Hydrogen and Helium, and of the effect of pressure on the spectrum of Helium, and we are indebted to Sir HERBERT JACKSON, K.B.E., F.R.S., for a tube of the conventional Plücker form which contained Helium in a very high state of purity. The tubes containing Hydrogen and Helium were filled in the same manner as those with flat cathodes, with the exception that the preliminary exhaustion was effected with an oil pump, the tubes being washed out repeatedly during the process of exhaustion with pure Hydrogen. This was admitted by heating in a Bunsen flame a palladium tube which was sealed into a glass tube connected with the apparatus. After the Helium had been admitted, the desired quantity of Hydrogen could be introduced in this way.

In all the experiments recorded, the tubes were excited by means of an induction coil capable of giving a 10-inch spark in air, with a mercury jet interrupter by means of which the discharge could be maintained uniformly over any desired period of time.

(V.) *The Helium Spectrum as a Function of Cathode Distance.*

We now enter upon a discussion of a series of plates of the Helium spectrum, taken at points whose distance from the cathode increased regularly. The tube was filled with Helium containing a little Hydrogen and Mercury, but the exposure given was not in any case sufficient to enable these impurities to appear on the enlarged photographs.

The essential features of the experimental arrangement are sufficiently evident without the necessity of a diagram. The cathode was flat, and was arranged with its length parallel to the plane of the slit of the spectrograph. By moving the vacuum tube in a direction perpendicular to the plane of the cathode, light from any desired region of the tube could be allowed to enter the slit and collimated in the usual manner. It has not been possible to isolate the spectrum of each region with great purity, but the slight overlapping of the effects of consecutive regions, which could not be avoided, does not affect the conclusions subsequently reached.

A series of eight photographs will be discussed. The first relates to the region immediately in front of the cathode, and the others to regions at successive distances of 1 mm. from this region. In the first five photographs the photographic intensities are all directly comparable, as they were all taken on the same plate, with two hours' exposure in each case. The other three were necessarily taken on a different plate, and though directly comparable among themselves, are not necessarily so with regard to the former set. At the same time, serious differences in the behaviour of the two plates are not to be expected, for they were selected from the same batch of plates.

The experimental measures of the heights of the various lines in each case are given in the following table, together with the density gradients of the wedge per millimetre at each wave-length, determined from the graph of density gradient in the manner already described. The table contains all the experimental data from which the ensuing conclusions are drawn. As these conclusions are of a very general nature, it was thought necessary to give the measurements relating to one set of photographs in complete detail.

The photographs are described by Roman numerals.

TABLE I.

λ.	d_λ.	Photograph I. at cathode.	Photograph II. at 1 mm.	Photograph III. at 2 mm.	Photograph IV. at 3 mm.	Photograph V. at 4 mm.	Photograph VI. at 5 mm.	Photograph VII. at 6 mm.	Photograph VIII. at 7 mm.
		h.	h.	h.	h.	h.	h.	h.	h.
6678	0·329	7·7	12·7	12·3	10·8	7·4	5·2	2·9	—
5876	0·396	9·4	13·1	13·6	13·2	11·1	9·5	7·9	3·4
5047	0·414	—	2·3	1·2	—	—	—	—	—
5015	0·415	8·7	12·2	11·3	8·9	6·0	4·3	2·5	—
4922	0·415	4·0	7·2	6·9	5·4	3·3	1·7	—	—
4713	0·420	4·0	8·0	7·8	6·0	3·9	1·8	—	—
4686	0·421	—	0·6	—	—	—	—	—	—
4472	0·453	10·0	13·4	13·2	12·7	11·2	9·8	8·1	3·9
4437	0·461	—	2·0	—	—	—	—	—	—
4388	0·475	3·3	5·2	5·3	4·8	3·8	1·9	1·1	—
4144	0·569	—	1·8	1·7	just seen	—	—	—	—
4121	0·582	—	2·0	2·0	just seen	—	—	—	—
4026	0·650	3·2	5·4	6·0	5·7	4·2	3·0	1·9	—
3965	0·707	2·0	3·3	3·3	2·1	just seen	—	—	—
3888	0·815	4·9	6·4	6·2	5·2	4·1	3·0	2·4	—

The magnification of the various photographs was not completely identical in all cases. On the original plate, the distance between the lines $\lambda\lambda$6678, 3888, was 44·95 mm. If this distance be measured on any individual photograph, its magnification m is deduced by simple division. On photographs I.–V. inclusive, we found m = 3·181, and on photographs VI.–VIII., m = 3·159.

Some of the Helium bands appear on the intermediate photographs, though absent very close to the cathode, and again at some distance from it. They are, in fact, only shown on the photographs IV.–VII., according to the details set forth in Table II. The wave-lengths are only rough values serving to identify the individual bands, and the values of d_λ are obtained as before from the calibration curve of the wedge. We merely record in the table some of the more conspicuous examples of these bands, as an illustration of their behaviour. We do not propose to discuss them, for they are in reality band heads consisting of a large number of nearly overlapping lines, and

the interpretation of the exact meaning of the intensities requires considerations which are not strictly relevant to the present communication.

TABLE II.—Helium Bands.

λ.	d_λ.	Photograph IV. at 3 mm.	Photograph V. at 4 mm.	Photograph VI. at 5 mm.	Photograph VII. at 6 mm.
		h.	h.	h.	h.
4650	0·423	3·1	3·5	2·9	2·5
4546	0·439	just seen	1·2	1·0	just seen
4459	0·456	1·2	1·7	just seen	—
4447	0·459	1·1	1·4	just seen	—
4427	0·464	2·2	2·5	1·5	1·2
4414	0·468	2·6	2·9	2·0	1·8
4399	0·471	2·2	2·5	1·7	1·1
4336	0·490	—	1·1	1·5	0·9

For a line taken twice on the same plate, but coming from different regions of the discharge tube, a direct comparison of its heights in the two cases is of no value as an indication of relative intensities, for the difference in height corresponding to any definite intensity-ratio in the two cases depends very much upon the density gradient of the wedge, whose variations along the spectrum are considerable. We must accordingly, as a preliminary to any discussion, obtain the photographic intensities of the lines in all cases, according to the formula

$$\log_{10}^{-1}(d_\lambda h_\lambda/m),$$

for these, as we have seen, are strictly comparable for the same line on the same plate with two different conditions or regions of excitation. The photographic intensities of the series lines are given in Table III.

The results of calculation of the photographic intensities of the Helium bands, on the photographs which register them, are as given in Table IV.

In general, we may say, in connection with these bands, that although in a qualitative sense they are intensified or weakened together, according to the region from which the spectrum is photographed, this general correspondence is not strictly quantitative, the relative intensities of any band in two regions being dependent to a small extent on the wave-length. In other words, the regions of maximum emission of these bands, which can appear simultaneously with the series spectrum of Helium, are not identical. This question will not be discussed further in this communication, owing to the difficulty, already indicated, of interpreting the exact meaning of the intensity in this case. The table already sufficiently indicates the general nature of the phenomena presented by the band heads in this form of experiment.

TABLE III.—Intensities of Helium Lines.

λ.	Photogragh I. at cathode. — Photographic intensity.	Photograph II. at 1 mm. beyond. — Photographic intensity.	Photograph III. at 2 mm. beyond. — Photographic intensity.	Photograph IV. at 3 mm. beyond. — Photographic intensity.	Photograph V. at 4 mm. beyond. — Photographic intensity.	Photograph VI. at 5 mm. beyond. — Photographic intensity.	Photograph VII. at 6 mm. beyond. — Photographic intensity.	Photograph VIII. at 7 mm. beyond. — Photographic intensity.
6678	6·25	20·6	18·7	13·1	5·82	3·48	2·00	—
5876	14·8	42·8	49·3	44·0	24·1	15·5	9·77	2·67
5047	—	1·99	1·43	—	—	—	—	—
5015	13·65	39·0	29·8	14·5	5·24	3·67	2·13	—
4922	3·33	8·69	7·94	5·07	2·69	1·67	—	—
4713	3·37	11·4	10·7	6·195	3·27	1·73	—	—
4686	—	1·20	—	—	—	—	—	—
4472	26·55	80·9	75·7	64·4	39·4	25·4	14·5	3·62
4437	—	1·95	—	—	—	—	—	—
4388	3·11	5·97	6·18	5·21	3·69	1·93	1·46	—
4144	—	2·10	2·01	—	—	—	—	—
4121	—	2·32	2·32	—	—	—	—	—
4026	4·51	12·7	16·8	14·6	7·21	4·14	2·46	—
3965	2·78	5·41	5·41	2·93	—	—	—	—
3888	17·99	43·6	38·8	21·5	11·2	5·94	4·16	—

λ 3965 is just seen on V.

TABLE IV.—Intensities of Helium Bands.

λ.	Photograph IV. — Photographic intensity.	Photograph V. — Photographic intensity.	Photograph VI. — Photographic intensity.	Photograph VII. — Photographic intensity.
4650	2·58	2·92	2·44	2·16
4546	just seen	1·47	1·38	just seen
4459	1·49	1·75	—	—
4447	1·44	1·59	—	—
4427	2·13	2·32	1·66	1·50
4414	2·42	2·67	1·98	1·85
4399	2·12	2·34	1·79	1·46
4336	—	1·48	1·71	1·38

*Diffuse Series and Cathode Distance.**—In order to isolate the various phenomena of intensity distribution presented by the spectrum of Helium at different distances

* HICKS has proposed a new arrangement of Helium series, regarding P series as being in fact F series. We have thought it more convenient, however, to retain the older terminology in our discussion throughout, as we deal only with experimental results.

from the cathode, three entirely distinct lines of enquiry must be investigated. These are—

(1) The relative intensities of the successive lines of any one series, as a function of cathode distance.

(2) The relative intensities of corresponding lines of the Principal, Sharp and Diffuse series, either of Helium or of Parhelium, under the same circumstances.

(3) The relative behaviour of the Helium lines (double) and of the Parhelium lines (single) in the case of corresponding members.

The entire phenomena presented can be regarded as the result of a superposition of these three effects, each of which is in itself of considerable interest in connection with any theory of the origin of spectra. Such a general enquiry into one definite spectrum, such as that of Helium, is necessarily somewhat long, but the spectrum of Helium is, in many respects, so typical, and our knowledge of the origin of series is so doubtful, that it is evidently desirable to push the investigation to the extreme limit in this individual case. Only by the definite isolation of the three effects mentioned can further progress in the elucidation of the nature of spectra apparently be made, and quantitative measurements of intensity have not hitherto been sufficiently sensitive to small changes, for the purpose of obtaining definite conclusions on any one of these subjects.

In the present section, we confine ourselves to a discussion of the relative behaviour of successive lines corresponding to increasing term number in a Diffuse series. Two such series are available on the present set of photographs—the doublets characteristic of the Diffuse series of Helium, and the single lines classed generally as Parhelium. The necessary data with regard to these lines—in the case of Helium being the joint effect of the two components of the doublet in each case—are set forth in Tables V. and VI. For the time being, we do not consider the interesting question of the position, with respect to the cathode, of maximum emission of any one line of such a series, but only relative intensities in the series on each photograph, one particular line being arbitrarily chosen as 10 in every case. The results of this computation are as follows:—

TABLE V.—Diffuse Series of Helium.

Intensity λ.	Photograph I. at cathode.	Photograph II. at 1 mm.	Photograph III. at 2 mm.	Photograph IV. at 3 mm.	Photograph V. at 4 mm.	Photograph VI. at 5 mm.	Photograph VII. at 6 mm.	Photograph VIII. at 7 mm.
5876	10	10	10	10	10	10	10	10
4472	18	19	15	15	16	16	15	14
4026	3·0	3·0	3·4	3·3	3·0	2·7	2·5	not seen

In connection with the interpretation of this table, it is necessary to remark, in the first place, that the actual numbers themselves give no information in the absolute sense, or in the relative sense down one column, as to the relative intensities of the three lines in question, for the photographic plate is not equally sensitive in three regions. But the actual changes in the numbers from one column to another give decisive information, since the intensity of $\lambda 5876$ is reduced to a uniform scale. These changes are very small, though quite definite, even taking into consideration the fact that the numbers are derived from an exponential type of formula, and they cannot be regarded as within the error of observation and consequent calculation. To at least a close approximation, however, *the relative intensities in the Diffuse series do not vary with the distance from the cathode.*

The small variations which do occur present no striking regularity, and it is evident that the behaviour of the last three photographs, already stated to be on a different plate to the others, is not appreciably different in these regions, so that we have further justification for the supposition that the two sets of photographs are directly comparable. There is a small amount of evidence in the table, although it is not decisive, that a slight energy transfer to the longer wave-lengths takes place with increasing distance from the cathode, but if it be real, it is yet so small as to be a comparatively unimportant phenomenon. There is no effective transfer of energy along the Diffuse series of Helium with increasing cathode distance.

Small variations in the numbers are to be expected, for it is difficult to maintain complete uniformity in the experimental conditions over a long period, and the various photographs were necessarily taken at different instants. But such variations in the conditions from one photograph to another apply to all the series alike, and from the uniformity of the numbers in Table V. we may assume with confidence that they are small.

According to this conclusion regarding the absence of an energy transfer along the series, it is not difficult to show that the vanishing of $\lambda 4026$ on VIII. is to be expected. For on the basis of 10 for the photographic intensity of $\lambda 5876$, the average value for $\lambda 4026$ is 3·0. The actual photographic intensity of $\lambda 5876$ on VIII. is, from a preceding table (Table III.) 2·67. That of $\lambda 4026$ should therefore be, on this scale,

$$2{\cdot}67 \times 3{\cdot}0/10 = 0{\cdot}80.$$

Accordingly, for this line, if h_λ be its height,

$$10^{d_\lambda h_\lambda/m} = 0{\cdot}80$$

which is less than unity, and therefore h is negative. This signifies that the exposure is insufficient to show the line even on theoretical grounds. In fact, on the scale in Tables III. and IV. the minimum photographic intensity which can be visible is not zero but unity. This particular scale, according to the definition of

photographic intensity adopted is the *true scale*, and will be referred to as such in later parts of this communication.

We may now consider Table VI. which shows that the Diffuse series of Parhelium behaves in the present connection in a quite different manner. The arbitrary intensity 10 is ascribed to λ6678 in each case.

TABLE VI.—Diffuse Series of Parhelium.

Intensity λ.	Photograph I. at cathode.	Photograph II. at 1 mm.	Photograph III. at 2 mm.	Photograph IV. at 3 mm.	Photograph V. at 4 mm.	Photograph VI. at 5 mm.	Photograph VII. at 6 mm.	Photograph VIII. at 7 mm.
6678	10	10	10	10	10	10	10	absent
4922	5·3	4·2	4·2	3·9	4·6	4·8	absent	absent
4388	5·0	2·9	3·3	4·0	6·3	5·5	7·3	absent
4144	absent	1·0	1·0	just seen	absent	absent	absent	absent

There is an initial drop of intensity on II. down this series, more pronounced in the third member, which becomes weaker relatively to the second. The fact that λ4144 is not visible on I. is readily interpreted, for on this photograph, the true photographic intensity of λ6678 is 6·25, so that λ4144 would become invisible if its intensity on the arbitrary scale of the last table were less than 16, which it may readily be, by comparison with the remainder of the last table.

After this initial drop, a remarkable enhancement takes place in λ4388, which is not confined to the last three photographs, and which cannot therefore be interpreted as due to a difference in behaviour of the separate plate on which they were taken. The change is of a quite different order of magnitude from any change found in Table V.

On the apparent law followed by the rest of the table, the true intensity of λ4144 on IV. is found to be 1·2, which is in accordance with the fact that it is just visible. The intensities of this line on later photographs, even on the supposition of quite considerable enhancement after the manner of λ4388, are all less than unity, so that its disappearance is to be expected. The theoretical intensity of λ4922 on VII., on the same supposition, cannot exceed about 0·9 on the true scale, which is in accordance with its disappearance from this photograph. It is therefore true in general that the absence of lines in this series on the various photographs presents no disturbing feature.

The general conclusion regarding the Diffuse series of Parhelium is that, after an initial tendency to enhancement of the first member λ6678 at the expense of the others, taking place almost exactly at the extremity of the dark space, there is a subsequent transfer of energy of the series to the higher members, as the distance

from the cathode is increased. This phenomenon shows the Diffuse series of Helium and of Parhelium in definite contrast, and is the first clear indication we have obtained of a real difference of behaviour down the two series under the same sets of conditions and excitation. We may in this connection again recall the anomalous behaviour of $\lambda 4388$ in many celestial spectra.

Sharp Series.—The corresponding data, reduced to an arbitrary scale in each case, relating to the Sharp series of Helium, are contained in Table VII.

Table VII.—Sharp Series of Helium. Intensity Ratios.

λ.	Photograph I.	Photograph II.	Photograph III.	Photograph IV.
4713	10	10	10	10
4121	absent	2·0	2·2	just seen

The Sharp series of Helium evidently behaves like the Diffuse series in preserving a constant intensity ratio between consecutive lines, at least for a distance of 3 mm. from the cathode Taking the average ratio as almost precisely 5·1, we deduce, from the true intensities 3·4, 6·2, of $\lambda 4713$ on photographs I., IV., that the corresponding intensities of $\lambda 4121$ should be 0·7 and 1·2, of which the second should be just visible and the first invisible. This is in accordance with the observational data in Table VII. Thus the intensity ratio down the Sharp series does not appear to vary with the cathode distance.

The only members of the Sharp series of Parhelium shown on our photographs are $\lambda 5047$ and $\lambda 4437$, which only occur together on II. It is not therefore possible to examine the variations in their intensity ratio.

Principal Series.—In the region of the spectrum which we have examined, the only Principal line of Helium is $\lambda 3888$, so that no conclusion can be drawn in the present enquiry as regards the relative behaviour of the members of this series as the cathode distance is varied. But the Principal series of Parhelium contains two members in this region whose relative intensity on the various photographs is indicated in Table VIII.

Table VIII.—Principal Series of Parhelium.

λ.	Photograph I.	Photograph II.	Photograph III.	Photograph IV.	Photograph V.
5015	10	10	10	10	10
3965	2·0	1·4	1·8	2·0	just seen

The initial relative enhancement of the first member, practically at the end of the dark space—a definite feature of the Diffuse series of Parhelium—is shown prominently in this series also. As the distance from the cathode is increased further, this phenomenon disappears, and the second member becomes more intense, in a regular manner, with respect to the first.

This process appears to be continuous, for the true intensity of $\lambda 3965$ on this scale, on the supposition that the ratio 1·5 of IV. is preserved on V., becomes 1·0 on calculation, which is not sufficient to render it so visible as it actually is on Photograph V. Evidently, therefore, the increase of relative intensity of $\lambda 3965$ continues, until there is an actual relative enhancement with respect to the first photograph. The Diffuse and Principal series of Parhelium thus behave similarly.

The general conclusions, with which all the results hitherto detailed are in accordance, may be stated as follows :—

As the cathode distance is increased, there is no definite change of relative intensity in the components of any Helium series, with the possible exception of a slight enhancement of the first member in the Diffuse series at a considerable distance from the cathode.

Parhelium, on the other hand, is in striking contrast. Earlier members of its series are enhanced at the expense of later members at the extremity of the dark space. Beyond this point, the phenomenon is gradually reversed, until finally there is a definite enhancement of later members at the expense of those of lower term-number.

This difference of behaviour of the single-line and doublet series must be of importance to any discussion of their origin. From a general point of view, it appears to imply at least that the two sets of series are not produced from the same atoms.

(VI.) *Comparison of Principal, Sharp and Diffuse Series.*

Superposed on the phenomena investigated above is another of considerable interest—the variation in the relative intensities of corresponding members of the three series of Helium or of Parhelium. The conclusions already reached as to the uniformity of behaviour for example in the three series of Helium, render it unnecessary to discuss the validity of this comparison based on corresponding members, for the conclusions to be obtained in this section are not dependent, in consequence, on the particular corresponding members selected for illustration.

In the case of Helium, we shall select the lines $\lambda\lambda 5876$, 4713, 3888, as representatives of the three series, reducing the first to intensity 10 on a new scale for each photograph. The results are indicated in Table IX.

The intensity of the Sharp series, after a definite increase, again at the end of the dark space, continuously decreases with reference to that of the Diffuse, at first

TABLE IX.—Helium—Comparison of Series.

Series.	λ.	Photograph I.	Photograph II.	Photograph III.	Photograph IV.	Photograph V.	Photograph VI.	Photograph VII.	Photograph VIII.
Diffuse	5876	10	10	10	10	10	10	10	10
Sharp	4713	2·3	2·7	2·2	1·4	1·4	1·1	absent	absent
Principal . . .	3888	12·2	10·2	7·9	4·9	4·65	3·8	4·3	absent
Principal, Sharp .	—	5·3	3·8	3·6	3·5	3·3	3·4	—	—

rapidly as the distance increases, but afterwards more slowly. The true intensity of the line λ5876 on VII., VIII. is so small that λ4713 could not appear on these photographs unless this law were suddenly changed in this region, so that its absence presents no difficulty. The Principal series, on the other hand, is not relatively intensified at the end of the dark space, but is already decreasing in intensity. There is evidence of an ultimate reversal at some distance from the cathode (on VII.) but it is not conclusive.

The intensity-ratio of Principal and Sharp series exhibited in the last row of the table, clearly shows that the Sharp series tends to become stronger relatively to the Principal series, rapidly at the end of the dark space, and afterwards very slowly. These phenomena are very definite.

It is perhaps desirable again to point out that the actual numbers in a table of this kind are in no way a representation of the energy emission in the various wave-lengths, owing to the curve of sensibility of the photographic plate. Only the change from one column to another has any significance in the present enquiry.

In the discussion of Parhelium from the same point of view, we may confine attention to the lines λλ6678, 5047, 5015, belonging respectively to the Diffuse, Sharp and Principal series. The intensity of λ6678 is in each case reduced to 10.

TABLE X.—Parhelium. Comparison of Series.

Series.	λ.	Photograph I.	Photograph II.	Photograph III.	Photograph IV.	Photograph V.	Photograph VI.	Photograph VII.	Photograph VIII.
Diffuse	6678	10	10	10	10	10	10	10	10
Sharp	5047	absent	0·96	0·76	absent	—	—	—	—
Principal . . .	5015	21·8	18·9	15·9	11·1	9·0	10·5	10·6	absent

We may consider, in the first place, the cases of absent lines. The true intensity of λ6678 on I. is 6·25, and the absence of λ5047 from this photograph merely indicates

that its intensity on the true scale does not exceed unity, and therefore on the present scale does not exceed 10/6·25 or 1·6. Comparison with the remainder of the table shows therefore that its absence is to be expected if the drop of intensity from I. to II. is not of a different order from that found in any other series. The disappearance of the same line from IV. and later photographs is also to be expected, unless a great increase of its relative intensity takes place suddenly at this point.

In the case of Parhelium, the Sharp and Principal series decrease in intensity as compared with the Diffuse series, without the temporary reversal of this phenomenon, at the end of the dark space, found in the case of Helium. The apparent reversal at a considerable distance, found in the case of Helium on one plate of the Principal series and stated not to be decisive, is repeated on two plates in the Principal series of Parhelium (VI., VII.) and now appears to be real. Very considerable exposures, however, would be necessary at greater distances in order to establish the fact that the phenomenon continued to occur. We have preferred, in the experiments recorded in this communication, to confine attention to a series of photographs taken with identical duration of exposure.

It is difficult to draw any conclusions, in the case of Parhelium, with regard to the relative transfer of energy between the Sharp and Principal series, for the former is only visible on two photographs. The only definite difference of behaviour with regard to Helium and Parhelium thus appears to lie in the region at the end of the dark space, where there is a temporary relative diminution of the Diffuse series of Helium, but not of Parhelium.

(VII.) *Comparison of Helium and Parhelium.*

A related problem of some interest is the determination, on some precise basis, of the relative changes which take place in the corresponding doublets (Helium) and single lines (Parhelium) in the spectrum. We have seen in the last section that the relative phenomena of the three series are the same in general in each case, except for a small difference on photograph II. The best standard of comparison is apparently given by the leading lines of the three series in each case.

We accordingly compare $\lambda\lambda$5876, 6678 as the leading lines of the two Diffuse series, $\lambda\lambda$4713, 5047, for the Sharp series, and $\lambda\lambda$3888, 5015, for the Principal series. Intensities in the doublet series are all reduced to 10.

The disappearance of 6678 on VIII. is in accordance with a still further reduction of its intensity on this scale, below 2·05, so that the decrease of relative intensity persists to the extreme photograph. There is a reversal at the end of the dark space on II. in the usual manner, the conditions of emission in this region evidently possessing special features which affect all the lines in the spectrum. Apart from this effect, the Parhelium Diffuse series steadily decreases in intensity, with increase of distance from the cathode, relatively to the Helium Diffuse series. The phenomenon

TABLE XI.—Helium and Parhelium.

Series.	λ.	Photograph I.	Photograph II.	Photograph III.	Photograph IV.	Photograph V.	Photograph VI.	Photograph VII.	Photograph VIII.
Diffuse	5876	10	10	10	10	10	10	10	10
	6678	4·22	4·81	3·80	2·98	2·41	2·25	2·05	—
Sharp	4713	10	10	10	10	10	10	—	—
	5047	—	1·75	1·33	—	—	—	—	—
Principal	3888	10	10	10	10	10	10	10	—
	5015	7·59	9·00	7·69	6·74	4·68	6·18	5·12	—

of the dark space is shown definitely also in the Principal series of Parhelium, which at this point becomes almost as intense as that of Helium. Subsequently the decrease of the Parhelium spectrum is shown definitely until we arrive at VI., where another temporary reversal occurs. Although the photographs VI.–VIII. may not be strictly comparable with the others, the phenomenon appears to be real, for it corresponds to similar effects in previous comparisons of series made in this communication, which are not restricted to special ranges of wave-length in which the plate on which VI.–VIII. were taken might have special properties. Moreover, it does not occur at all in other series, for example the two Diffuse series of the present section, where there is no sudden change in the character of the numbers characterizing λ6678 on passing from V.–VI.

It seems necessary to conclude that there is a region, distant about 5 mm. from the cathode in the present experiment, where, as at the extremity of the dark space—1 mm. from the cathode—the conditions of excitation reach some form of critical point, with a consequent change in the nature of the law of intensity variation of certain lines and series with cathode distance. In particular, there is a tendency for relative enhancement of the Principal series of Parhelium, but not the Diffuse series, at this point.

(VIII.) *Regions of Maximum Emission.*

The regions in the tube from which individual spectral lines are radiated with greatest intensity are of considerable importance in connection with theories of the origin of spectra. The present measurements enable us to obtain some quantitative data with regard to many lines in the spectrum of Helium. We do not attempt to discuss all the lines from this point of view, the exposure being in many cases only sufficient to show some of the lines on one or two photographs, so that no graphical or other method can be used to determine the exact law which connects their intensities with the distances from the cathode, enabling the positions of the maxima to be read off the curve of intensity or calculated by analysis. Moreover, it is sufficient, for a

general survey of the question, to discuss only typical lines, in view of the previous tables. For example, in the Diffuse series of Helium, we found that the ratios of intensity of the three members visible, $\lambda\lambda 5876$, 4472, 4026, remained effectively constant over the whole range of the photographs, so that their maxima must occur at the same place, and the examination of $\lambda 5876$ is sufficient. The photographs all had the same duration of exposure, and being on the same plate, those numbered I.–V. are strictly comparable even as regards the intensities shown by an individual line, except in so far as variations—already seen in another connection to be very small—may occur owing to the difficulty of maintaining uniform conditions of excitation throughout the exposures of the various photographs. We have, moreover, in the preceding sections found no reason to believe that the other plate, on which VI.–VIII. were taken, is in any important respect different from the first. We shall therefore assume, as a basis, that the sequence of eight photographs can be compared as regards the intensity of an individual line.

The sequence of intensities of $\lambda 5876$, which we may take as the first example, is from Table I.

$$14{\cdot}8, \quad 42{\cdot}8, \quad 49{\cdot}3, \quad 44{\cdot}0, \quad 24{\cdot}1, \quad 15{\cdot}5, \quad 97{\cdot}7, \quad 2{\cdot}67,$$

and it is at once evident that the seat of maximum emission is at about 2 mm. from the cathode.

Attempts to fit these numbers to an interpolation formula of the type

$$\mathrm{I} = a + bx + cx^2 + \ldots$$

where I is the intensity and x the cathode distance, are not successful. It is in fact evident from the later members of the sequence that the law is partly exponential. The sequence of logarithms of intensity is found to be, to base 10,

$$1{\cdot}17, \quad 1{\cdot}63, \quad 1{\cdot}69, \quad 1{\cdot}64, \quad 1{\cdot}38, \quad 1{\cdot}19, \quad 0{\cdot}99, \quad 0{\cdot}43,$$

and these also, especially when the dark space is included, do not fit well into an interpolation formula of the above type. It is probable that any law, in order to be valid over this wide region, must be somewhat cumbrous. The dark space must, in fact, be left out of consideration in obtaining such a formula, and an example of a three-constant one is

$$\log_{10} \mathrm{I} = a + bx + cx^2, \; a = 1{\cdot}452, \; b = 0{\cdot}235, \; c = 0{\cdot}0575,$$

which gives the second, third, fourth, and sixth numbers accurately and 1·47 for the fifth, whose actual value was found to be 1·38. The formula is not very good, but sufficient for our purpose, and the calculated maximum is at the point

$$x = b/2c = 2{\cdot}05 \text{ mm.}$$

Other formulæ of interpolation which have been used, though not described in this communication, give 2·0 mm. as the position of maximum emission of the Diffuse series of Helium in these experiments.

In the case of other series, the position is not the same for each member, and the best method of studying the phenomena is apparently by means of a graph, as shown in fig. 2. The abscissæ are distances from the cathode, while the ordinates represent photographic intensities of lines at these distances. Graphs for several of the more important lines in the spectrum are given. The general features of these typical curves can at once be seen. The close resemblance between the leading lines of the two Principal series, $\lambda\lambda$3888, 5015, is very strikingly different from the behaviour of the curves obtained for lines of the associated series, which in themselves are similar.

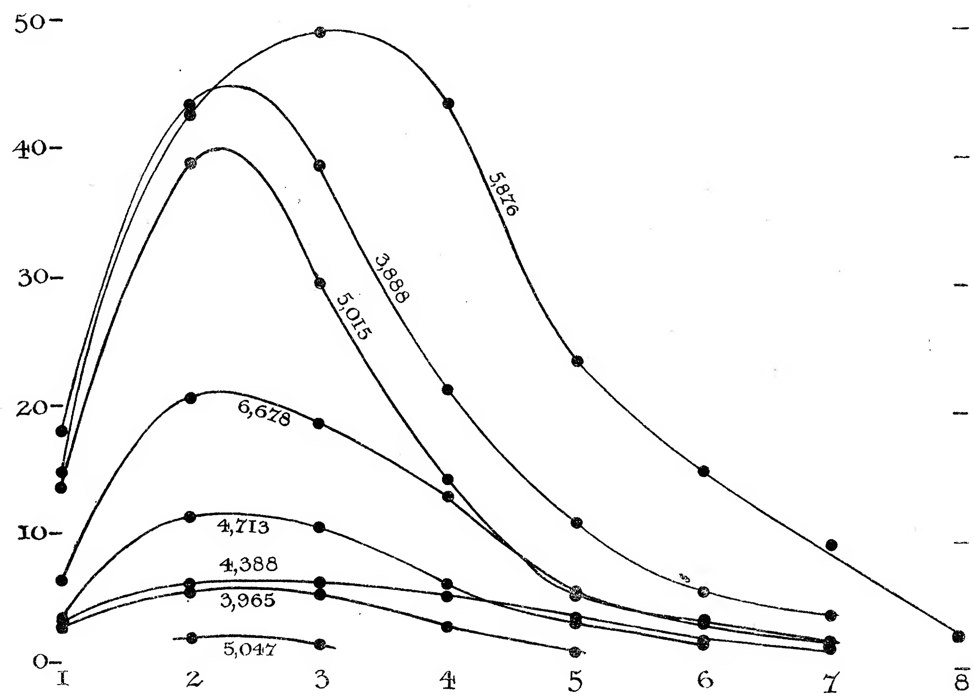


Fig. 2.

A qualitative survey of the variation in distribution of the lines in front of the cathode is given in fig. 3. This plate was obtained by photographing, without the wedge, the glow in front of the cathode, which was in this case perpendicular to the length of the slit. It presents certain remarkable features which have not hitherto been discussed. In order to enhance the effects, the plate has been reproduced by processes introducing excessive photographic contrast which, whilst accentuating the outstanding features, have obliterated fainter lines such as Hα and Hg λ5461, which were clearly visible on the original plate. It will be noticed that whilst the Helium lines start from the cathode and fade away continuously, the Hydrogen lines show a very definite " dark space." The Mercury lines reach their maximum of intensity at

a still greater distance from the cathode. Of particular interest is the behaviour of the characteristic "spark" line λ4686, and the band spectrum, of which only the more prominent heads are visible.

It has been known for some time that the band spectrum and λ4686 appear in the

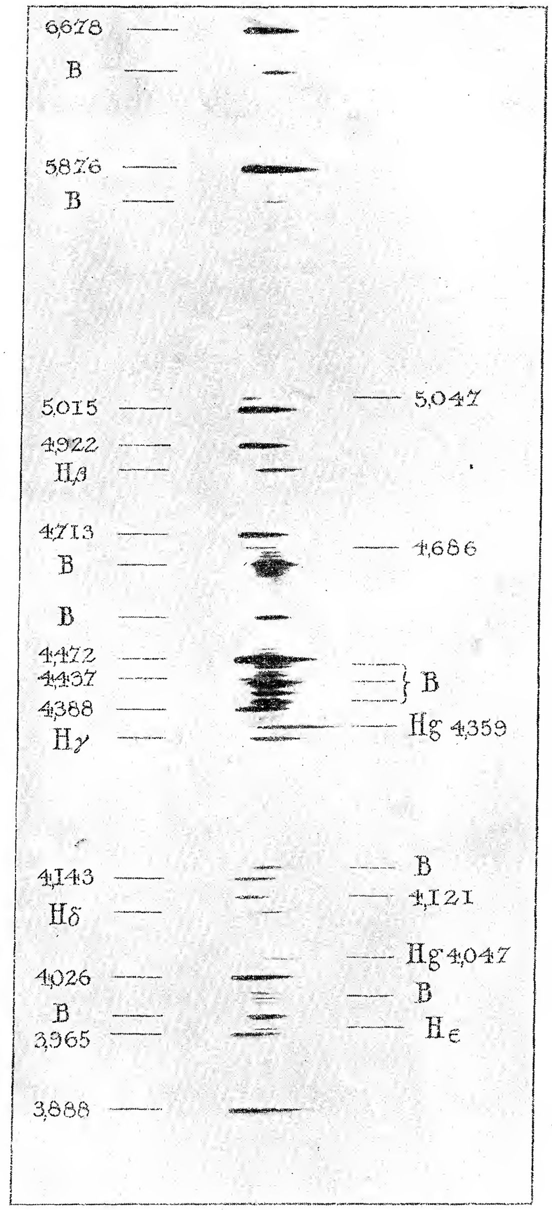


Fig. 3.

glow around the cathode. Whilst confirming this, we see that the band spectrum is localised in a restricted region at some distance from the cathode. On the other hand, λ4686 has its seat of maximum emission in a region where the band spectrum is only just visible, but it is interesting to note that over a definite region λ4686 and

the band spectrum appear together. It seems possible that this mode of observation will be of use in the resolution of complex spectra into series.

The somewhat narrow region to which the band spectrum is confined would seem to imply that the conditions of excitation which give rise to this spectrum fall between very restricted limits.

(IX.) *The Spectra of Mixed Gases.*

A considerable amount of qualitative information has already been obtained by various investigators, who have examined the effect, on the spectrum of a gas, produced by impurities, or by a definite mixture with another gas. We have already referred to this work in our introductory section and in a preceding communication, in which we described some strictly quantitative results shown by the spectrum of Hydrogen when this gas is mixed with a certain amount of Neon. The effect on the spectrum of Neon, which may be expected to be in some sense complementary, of the large admixture of Hydrogen was not investigated on account of our lack of knowledge of the series relations in the Neon spectrum. In order to determine in what sense complementary effects occur in the spectra of the two mixed gases, it is necessary to select two gases whose series relations are known, and the present section of this communication details the experimental results obtained by our method of measurement, with a view to the discussion given in later sections.

In our experiments with mixed gases, we have not been able to eliminate as a source of error the possibilities of effects arising from small differences in pressure in the different tubes, but as the effects observed do not correspond to those which would accompany an alteration in pressure, we feel that the observed phenomena may be described as particular to the mixed gases.

We have made experiments on this subject in two cases, which present strikingly dissimilar phenomena. In the first case, the gas consisted mainly of Helium, with only a very small admixture of Hydrogen—sufficiently small, in fact, to justify the statement that practically only a trace of Hydrogen was present. In the second case, a considerable addition of Hydrogen to the Helium was made, so that the tube actually contained a "mixed gas," in the sense that the orders of magnitude of the quantities present were the same. For purposes of comparison, we also examined the spectrum, under like conditions, of the purest Helium which could be obtained, and which we have already mentioned. We shall refer to this as "pure Helium," and to a similar spectrum obtained with the purest available Hydrogen as that of "pure Hydrogen."

Allied to this investigation is another on the spectrum of Helium under very low pressure, and it is convenient to record and reduce the observations relating to this question with those relating to mixed gases, the mode of reduction being identical. In the subsequent discussion, they may also be taken together for the sake of brevity.

It does not appear to be necessary to add any further details of the experimental arrangements in these cases, which have been dealt with in an earlier section in general terms.

The magnification of all the enlargements in these cases was the same, the interval between λλ6678, 3888, being 147 mm. as against 44·95 mm. on the original plate. The magnification is therefore

$$m = 147/44{\cdot}95 = 3{\cdot}270.$$

The following notation will be adopted for brevity :—

(*a*) = Spectrum of pure Helium at very low pressure, the resistance of the tube corresponding to about 2 cm. alternative spark gap.

(*b*) = "Ordinary" spectrum of pure Helium from the capillary with 1 mm. dark space.

(*c*) = Spectrum of Helium containing a trace of Hydrogen, just sufficient to show the Hydrogen lines. Taken from the capillary (1 mm. dark space).

(*d*) = Spectrum as in (*c*), but with a larger admixture of Hydrogen.

Table XII. gives the observed heights of the various lines :—

TABLE XII.—Observations of Helium under Various Conditions.

λ.	d_λ.	Photograph (*a*).	Photograph (*b*).	Photograph (*c*).	Photograph (*d*).
		h.	*h*.	*h*.	*h*.
7065	0·233	absent	10·6	10·0	11·3
6678	0·329	5·3	18·0	17·9	16·8
5876	0·396	9·0	21·8	20·3	19·0
5047	0·414	absent	8·3	7·7	10·2
5015	0·415	9·4	16·6	14·8	15·8
4922	0·415	5·0	12·8	12·0	13·2
4713	0·420	6·3	15·5	14·4	16·6
4471	0·453	11·5	19·9	18·1	18·7
4437	0·461	absent	6·7	5·9	7·6
4388	0·475	4·2	10·1	9·3	10·0
4169	0·556	absent	1·2	absent	2·0
4144	0·569	absent	4·9	3·7	5·0
4121	0·582	absent	7·7	6·6	7·9
4026	0·650	4·0	9·2	8·4	9·4
4009	0·664	absent	0·9	absent	1·5
3965	0·707	2·2	6·6	5·3	6·4
3888	0·815	3·6	11·1	10·1	10·1

The next table (Table XIII.) gives the corresponding photographic intensities of the lines, as the results of calculation by the usual formula.

TABLE XIII.—Intensities of Helium Lines under Various Conditions.

λ.	Photograph (*a*).	Photograph (*b*).	Photograph (*c*).	Photograph (*d*).
	I.	I.	I.	I.
7065	absent	5·69	5·16	6·38
6678	3·41	64·7	63·2	49·0
5876	12·30	437	288	200
5047	absent	11·2	9·44	19·55
5015	15·6	128	75·7	101
4922	4·32	42·1	33·3	47·3
4713	6·44	97·9	70·6	135·5
4471	39·18	571·5	322	390
4437	absent	8·81	6·79	11·8
4388	4·07	29·3	22·4	28·4
4169	absent	1·60	absent	2·19
4144	absent	7·13	4·41	7·41
4121	absent	23·4	15·0	25·5
4026	6·24	67·5	46·8	73·8
4009	absent	1·52	absent	2·02
3965	2·99	26·7	14·0	24·2
3888	7·89	585	329	329

Helium Series under Various Conditions of Pressure and of Purity.—We may begin the discussion of the phenomena contained in the last table by a consideration of the Diffuse and Sharp series of Helium. The relative intensities of lines belonging to different series, including the classical example of λ5876 and λ5015 at low pressures, will be considered in a later section.

We shall for the moment confine attention to the question of energy transfer up or down the series, from one line to another of the *same* series, produced by very low pressure—as distinguished from "ordinary" conditions of pressure—or by admixture of a large or small quantity of Hydrogen. In each photograph we reduce the intensity of λ5876, in discussing the case of Helium, to 10 on any necessary scale, with corresponding calculations of the reduced intensities on the same scale, of λ4471 and λ4026. The results are shown, with the corresponding ones obtained in the same manner for the Sharp series—represented by the lines λλ7065, 4713, 4121—in Table XIV. There are three members in each case, and we have accordingly appended also the intensity ratio of the two other members, as they must also be compared with one another as well as with the first member. In the case of the Sharp series it has been more convenient to take λ4713 as the standard instead of λ7065.

In discussing these results we must, of course, take the ordinary spectrum of pure Helium given on photograph (*b*), and refer the others to this as a standard. Inspection of the table reveals the following main characteristics of these spectra :—Low pressure definitely enhances the line λ4471 with respect to λ5876, and at the

particular pressure we have adopted, its relative intensity is more than doubled. The importance of this result, from the point of view of the conditions of pressure occurring in nebulæ, is sufficiently evident, for the behaviour of this line in nebulæ as compared with $\lambda 5876$ is in the same sense. It is not unlikely that further reduction of the pressure may carry the process further, and this question forms an important subject for future investigation.

TABLE XIV.—Diffuse Series and Sharp Series (Helium).

λ.	Reduced photographic intensities.			
	(*a*) Low pressure.	(*b*) Ordinary.	(*c*) Trace of hydrogen.	(*d*) With hydrogen.
5876	10	10	10	10
4471	31·1	13·1	11·2	19·5
4026	5·04	3·69	1·63	3·69
Ratio	0·162	0·189	0·146	0·190
7065	absent	0·58	0·73	0·47
4713	10	10	10	10
4121	absent	2·4	2·12	1·88
Ratio	—	4·16	2·90	4·00

The relative intensity of $\lambda 4026$ with respect to D_3, on the other hand, is not altered so appreciably. With respect to $\lambda 4471$ this line is much reduced. It is evident that the phenomenon is not correctly described as a transfer of energy to the members of higher term number in the series, and therefore that the effect of low pressure cannot be classed with the phenomena of enhancement of $\lambda 4472$ which we recorded in a previous communication. For in these cases, the line $\lambda 4026$ also participated in the effect to a much greater extent, and even relatively to $\lambda 4471$.

Our conclusion must be that reduction of pressure in the tube can enhance the line $\lambda 4472$ to a great degree, but at the same time leaves other members of the series with nearly the same relative intensities. In the case of the Sharp series, the discussion is made rather more difficult by virtue of the disappearance of $\lambda 7065$ and $\lambda 4121$ from our plate at low pressure. But we can calculate the limiting intensities they can have. If their "true" intensity was unity in this case, while $\lambda 4713$ had its true intensity 6·44, they would be visible. On a scale of intensity 10 for $\lambda 4713$, they become visible if their intensity exceeds the value 10/6·44 or 1·55. We may accordingly assume that it is less.

Comparing this investigation with the fact of the existence of an intensity 2·4 on this scale, for the line $\lambda 4121$ in the "ordinary" spectrum, as in the table, it is evident that the phenomenon found in the Diffuse series is present here also, and to the same degree. In the case of nebulæ, the Sharp series of Helium is always very weak, but

the line λ4713 is well-known. Its behaviour under low pressure is, in the light of these experiments, strictly comparable with that of λ4471, and these lines are respectively the second members of the two series.

We may now take up the consideration of the effects produced by admixture of Hydrogen. There is in this case some quantitative information available in one direction. For in a previous communication, we discussed the effect produced on the spectrum of Hydrogen by the admixture of heavier gases, such as Helium and, more especially in that communication, Neon. It was found that a transfer of energy occurred in the Hydrogen spectrum under these circumstances from the members of lower to those of higher term number, and that, in the quantitative sense, this transfer, which could be measured very accurately, was considerable. We now consider the other side of the problem of inter-action of two gases, from the point of view of the heavier gas. The series arrangement in Neon being unknown, this could not be discussed previously, but the present data for Helium give a basis for discussion.

Passing now to the Diffuse series of Helium, as shown on photographs (*b*) and (*c*), and in Table XIII., the effect of a small quantity of Hydrogen is very marked. On a scale which preserves λ5876 with intensity 10 in each case, the intensity of λ4471 is 19·5 in pure Helium, but only 11·2, or only half as great, when a trace of Hydrogen is inserted. Moreover, λ4026 falls in intensity from 3·69 to 1·63—or less than half. In fact, it falls even relatively to λ4471, so that the result implies a definite energy transfer of considerable amount towards the members of low term number in the series, and more especially towards λ5876. This is precisely the converse phenomenon to that found in Hydrogen itself when mixed with a large quantity of Neon or Helium.

The Sharp series of Helium behaves in the same manner, and to an extent which is nearly equivalent, in the quantitative sense. While λ4713 is retained at 10, the higher member—of lower term number—λ7065 is enhanced from 0·58 to 0·73, in the proportion 3·2. At the same time λ4121 falls from 2·4 to 2·1—a change quite outside the possible limits of experimental error in this mode of measurement. We may therefore state, in general terms, that the effect of a trace of Hydrogen is to throw the energy in the two series much more completely into members of lower term number, so that each is reduced in intensity relatively to any earlier member.

A comparison of photographs (*b*) and (*d*) indicates the effect of a large admixture of Hydrogen. This is quite different, for the Diffuse series shows at once a tendency for transfer of energy in the opposite direction. For on the equivalent reduced scales, λ4472 is enhanced only from 13·1 to 19·5, and λ4026 is unaltered. The phenomenon is therefore in this case not at all defined as a transfer in increasing amounts to the members of higher term numbers. It is apparently the resultant of a combination of this process with the opposite process, resulting in a direct and special enhancement of λ4472 of the same nature as we found with low pressure.

But the important fact for our present enquiry is that the role played by a large quantity of Hydrogen is directly contrary to that played by a small trace, and we may argue that the mechanism of inter-action of the two gases is quite different in the two cases. A definite phenomenon has been quantitatively isolated which demands for its appearance only a spectroscopic "trace" of one of the acting gases.

This reversal of the effect of a trace of Hydrogen, by the admixture of more Hydrogen is, however, interesting in another way, for it introduces us to a striking difference of behaviour between Diffuse and Sharp series. Inspection of Table XIII. indicates that the line λ7065 shows very little tendency to change in relation to λ4713 by the action of this Hydrogen—or at least that the change in the Diffuse series is of quite another order. Moreover, the change among the lines λλ7065, 4713, 4121, though comparatively small, is quite definitely present as a combination of two effects. For λ4121 is reduced relatively to λ4713, as by the effect of the trace of Hydrogen, while λ4713, as against λ7065, is quite definitely enhanced. It seems that the Sharp series under these circumstances is just ceasing to show the first phenomenon, due to the trace of Hydrogen, and commencing to show the second, so that if the quantity of Hydrogen were increased yet further, the second might predominate. In other words, the essential difference between the Diffuse and Sharp series is that in the latter case a more considerable admixture of impurity is needed to produce the effects observed in the Diffuse series. Sharp series are in fact sensitive, to an equal extent with Diffuse series, to the influence of a trace of Hydrogen, but not to a comparable degree to the different mechanism of interaction with large quantities of Hydrogen. We feel no doubt that the available data can be summarised in this way, for the phenomena shown by the Parhelium spectrum follow the same course throughout.

The Principal series of Helium, showing only one member λ3888 is not, of course, capable of test in this manner by the present experiments.

Principal Series under the same Conditions.—The Diffuse series of Parhelium contains five members on some of our plates, and we can therefore make by its use a much more exhaustive test of the conclusions outlined in the preceding section. It is also possible to obtain information relating to Principal series, and this will be our first object in the present section. Since there are only two visible members, in these experiments, the Table (XV.) is very short.

TABLE XV.

λ.	(*a*).	(*b*).	(*c*).	(*d*).
5015	10	10	10	10
3965	1·92	2·08	1·85	2·4

By comparison of (*a*) and (*b*), we see that the second member of the Principal series is not enhanced by low pressure relatively to the first. It is in fact definitely reduced. This series behaves accordingly in a different manner from the others. It would seem that the phenomenon found in the other case—that of a selective transfer of energy—is not produced.

We may also notice that the selective enhancement at low pressure of the higher members in any one series which, as we have seen, must be regarded as a phenomenon relating to the Diffuse and Sharp series, but more especially to the former, is one which would be expected on theoretical grounds from a theory such as that of BOHR, which regards lines of higher term number as due to the passage of atoms between "stationary states" of relatively large atomic radius—a state of things to be expected with greater frequency under the influence of a considerable reduction of pressure. We may recall, for example, BOHR's explanation of the great extent of visibility of BALMER's series of Hydrogen lines in the solar spectrum. It is noteworthy, in this connection, that the Diffuse series of elements are those in which the Rydberg phase constant is nearly unity, so they accord very closely, in quite general terms, with the present principles underlying BOHR's theory. So far as the present investigation is concerned, the quantitative examination of the alteration of the spectrum of Helium produced by reduction of pressure lends a certain amount of support to BOHR's theory, at the same time, however, implying that the theory in question, if in its general basis correct as regards Diffuse series, does not furnish any interpretation of the origin of Principal series, in which the Rydberg phase is usually widely different from unity. We do not, however, propose to discuss this question further at the present time, as evidence in the other direction can be adduced also. For example, we showed in a previous communication that the Balmer series of Hydrogen lines does not in fact possess the characteristics of a Diffuse series, for the separations of the doublets which compose it are not constant as regards wave number, but are, on the other hand, appropriate to a Principal series. The question of the relation of our results to BOHR's theory must therefore be left unsolved at the present time, and we prefer to summarise the selective effect of low pressure in individual series in the Helium spectrum into the statement that while in the Diffuse and Sharp series, there is an energy transfer to higher term numbers, the effect on the Principal series is in the opposite sense.

We have not, of course, yet examined the effect of low pressure on the Diffuse and Sharp series of Parhelium. This examination will be given briefly after the corresponding tables have been exhibited, and will be found to correspond exactly to the similar effects observed in Helium. Meanwhile, we may complete the discussion of Principal series by a short survey of the change produced by admixture of a light gas such as Hydrogen.

Referring again to Table XIII., photograph (*b*) and (*c*), we find that the influence of a trace of Hydrogen decreases $\lambda 3965$ in intensity relatively to $\lambda 5015$. The original

intensity is, however, more than restored by the addition of more Hydrogen. This behaviour is precisely similar to that shown by the Diffuse series of Helium, although the actual changes are of a smaller order of magnitude.

Diffuse and Sharp Series of Parhelium.—We stated at the beginning of the last section that the Diffuse series of Parhelium supplied a peculiarly exhaustive test of the more general applicability of some of our conclusions. The main details regarding the intensities of the lines under the conditions in question are given in Table XVI.

TABLE XVI.—Diffuse Parhelium under Various Conditions.

λ.	(*a*) Low pressure.	(*b*) Ordinary.	(*c*) With trace of hydrogen.	(*d*) Mixture.
6678	10	10	10	10
4922	12·7	6·51	5·27	9·66
4388	11·9	4·53	3·55	5·80
4144	absent	1·10	0·70	1·51
4009	absent	0·23	absent	0·41

The enhancement of λ4922 and λ4388 relatively to λ6678 is at once obvious, by inspection of the table, in the case of the low pressure spectrum. It is in fact even more remarkable than in the corresponding Helium series. Moreover, λ4388 is enhanced relatively to λ4922. The remarks which we made earlier regarding λ4472 in the nebular spectrum apply with greater force to λ4388. The behaviour of these two lines in nebulæ is thus correlated, in the light of these experiments, by the fact that nebulæ are in a state of extremely low pressure—and certainly much lower than in the present investigation, so that the relative enhancement of λ4471 and λ4388 may be expected to be much greater. But the degree to which the phenomenon occurs, even with the present exhaustion of the tube, is sufficiently convincing.

As in the case of the Diffuse series of Helium, this effect again cannot be described as a continuous transfer of energy down the series, for if this were the case, λ4144 would become visible when enhanced to a greater degree than λ4388. It is actually invisible, and calculation shows that this fact implies that its intensity relatively to λ6678 is not more than doubled. We must therefore repeat the former conclusion that the strong enhancements of particular lines at low pressure are peculiar to these lines, and in fact to the three lines λλ4471, 4922, 4388, of the two Diffuse series. Under still lower pressure, λ4922 may be expected to become quite subordinated to λ4388, which is already as strong in our experiments, and in the very low conditions of pressure in nebulæ, λλ4471, 4388, should therefore be the two most prominent Helium lines of the Diffuse series. This is a well-known fact of observation in astrophysics.

We may now take up the consideration of the effect of a trace of Hydrogen. Inspection of the table is almost sufficient to show that the energy-transfer to longer

wave-lengths found in Diffuse Helium is repeated in the corresponding series of Parhelium. For λ4922 is reduced from 6·5 to 5·3. λ4388 is even more reduced from 4·5 to 3·5, and λ4144 from 1·1 to 0·7. In fact each is reduced relatively to all its predecessors in the series. We are in this case dealing with a phenomenon of a different type to that caused by variation of pressure, and as suggested in connection with Diffuse Helium, we prefer to restrict the term "energy-transfer" to cases in which the change of intensity of a line is greater than, or less than, the change in all its predecessors in the series.

The effect of a large admixture of Hydrogen is again, as in Helium, directly contrary to the effect of a small trace just discussed. There is an actual enhancement of the members of higher term number in the series.

There remains the necessity of verifying the fact that the Sharp series of Parhelium presents no exceptional features, and of observing from a consideration of Hydrogen lines emitted in the presence of Helium in these experiments—they have been observed in presence of Neon in an earlier communication—the simultaneous effect on the lighter component of the mixture.

For consideration of the Sharp series of Parhelium we have calculated, reducing λ5047 to intensity 10 in each case, the following intensities of the next member, λ4437 :—

λ4437, intensity 7·87 in the ordinary spectrum, 7·2 with a trace of Hydrogen, and 6·03 with more Hydrogen. The reduction of the second member by a trace of Hydrogen is again evident, though not very strongly. A slight further reduction is manifest with more Hydrogen, but the changes are so small that we may conclude, from these data, that Parhelium presents no contradiction to the view that the reversal of energy-transfer in the Sharp series takes place at a later stage of continued admixture of Hydrogen than in the Diffuse series. The present numbers appear to indicate, as did those for the Sharp series of Helium, that the reversal is on the point of taking place.

The Spectrum of Hydrogen.—In the following table (Table XVII.) the results are given for the spectrum of pure Hydrogen, taken in the ordinary way from a capillary

TABLE XVII.—Hydrogen.

λ.	d_λ.	Pure.		Mixed with Helium.		Ratio of photographic intensities.
		h.	Photographic intensity.	*h*.	Photographic intensity.	
H_α	0·343	9·9	10·9	17·0	60·7	5·6
H_β	0·416	7·8	9·82	14·6	72·1	9·2
H_γ	0·490	5·3	6·22	11·1	46·9	7·4
H_δ	0·595	2·0	2·31	5·4	9·60	4·1
H_ϵ	0·705	absent	—	1·3	1·91	—

with a pressure of 1 mm. of dark space, and the spectrum of Hydrogen as shown under the same circumstances in conjunction with that of Helium on photograph (*b*). A comparison of these tables supplies the necessary basis for a determination of the effect of mixture on the spectrum of the lighter gas.

The magnification m was in each case 3·270. The transfer of energy towards the higher term numbers is very evident, although in the later members, H_δ, &c., it is not completely established. The effect on the lighter gas is therefore the same as that on the heavier, when the quantities of each present in the mixture are comparable. In fact in a comparable mixture of the two gases there is a tendency in both cases towards relative diminution of the leading lines of series, and towards, in general, a shift of the energy of emission towards the violet.

It is now clear that the mechanism of this effect must be wholly different from that operative when only a small quantity of Hydrogen is present. For in the latter case, the effect of a trace of the lighter gas on the spectrum of the heavier one is to transfer the energy emission of the latter towards the leading members of series, while a trace of the heavier gas transfers the energy emission of the lighter gas away from the leading members.

(X.) *Comparison of Different Series under Low Pressure.*

We have, in earlier sections, discussed the relative behaviour of different lines *of the same series* under various conditions, and have restricted the use of the term "selective" to the enhancement or reduction of any line relatively to other lines of the same series. Phenomena which involve the relative behaviour of *different* series, or corresponding members thereof, are, in many cases, of even greater significance. The classical example is the behaviour of λ5015—belonging to the Principal series of Parhelium—under low pressure, as compared with λ5876, of the Diffuse series of Helium. It is well recognised that λ5015 in particular is essentially a low pressure line. In the following table (Table XVIII.) the four lines, $\lambda\lambda$5876, 4472, 5015, 4388, are considered together (i) at a pressure corresponding to 1 mm. dark space and (ii) at low pressure. The intensities are taken from previous tables and reduced in each case to a scale on which the intensity of λ5876 is 10.

TABLE XVIII.

λ.	At 1 mm. dark space.	Low pressure.
5876	10	10
4472	13·1	31·8
5015	2·93	12·7
4388	0·67	3·30

The other three lines are all greatly enhanced with respect to λ5876. They were selected because of the astrophysical interest attaching to these lines. The greatest degree of enhancement occurs in λ4388, which would suggest the conditions obtaining in nebulæ, but there is an almost equivalent enhancement—producing in fact an actual greater intensity—in λ5015. In a previous section of this communication, we concluded that the relative behaviour at low pressure, as regards their own individual series, of λλ4472 and 4388, reproduced the intensity relations found in the nebulæ. But the corresponding effect for λ5015 shows that we have not isolated the conditions which produce the nebular intensity relations in this way. Some further condition, which is capable of producing a diminution of intensity in λ5015—with perhaps a further enhancement of λλ4472 and 4388—must be superposed. A consideration of the results of a previous communication* relating to the effect of a condensed discharge, suggests that the great intensity of excitation obtaining under such conditions may be the necessary co-operative condition. It is at least evident that if we could superpose the effects separately obtained under the two conditions—very low pressure and the condensed discharge—a very close approximation to the actual intensity relations of the Helium spectrum in nebulæ would be realised.

(XI.) *Further Relations of Different Series.*

In the previous section we have considered one special problem of interest to astrophysicists—the reproduction in the laboratory of the intensity distribution among Helium lines as known in nebulæ. It is to a great extent a problem involving mainly the lines whose behaviour is in some degree exceptional. But there are in addition a number of relations which may be described as more normal, and these are of considerable interest in connection at least with laboratory spectra. They may all be studied by relating together only one individual line of each of the series—the first member except in one case, the Sharp series of Helium, where it is more convenient to use λ4713 rather than λ7065. Apart from such exceptional lines as λλ4472, 4388, the general intensity relations of the series are sufficiently defined by those of the particular representatives selected below for comparison. It is of course understood that all the effects now to be discussed are superposed on the various purely selective effects—selective as regards one particular series in each case—discussed in all sections, after the experimental description, except the last, which deals with a purely special problem.

We shall take, in the first place, the available data on the general emission in the three Helium series under various conditions, these series being represented by the lines λ5876 (Diffuse), λ4713 (Sharp) and λ3888 (Principal). The arbitrary intensity of the first is 10 in every case in the table (Table XIX.).

* *Loc. cit.*, p. 259.

TABLE XIX.—General Emission of Helium Series.

Series.	λ.	Pure Helium.	Low pressure.	Helium and trace of hydrogen.	$He + H_2$.
Diffuse	5876	10	10	10	10
Sharp	4713	2·24	5·24	2·45	6·77
Principal	3888	13·4	6·41	11·42	16·45

It is perhaps desirable to remark again at this point that the numbers in any one column give no indication of the relative emissions of energy in these wave-lengths, the properties of the plate being widely different in the three regions of the spectrum concerned. Comparison is justifiable in rows, but not in columns.

Low pressure produces a considerable enhancement of the Sharp series relatively to the Diffuse series—in fact the intensity is doubled—and a simultaneous reduction of the Principal series of an equivalent magnitude.

A trace of Hydrogen produces only small differences in the relative emission of the three series, as determined by these lines. The Sharp series is slightly enhanced, and the Principal series to a somewhat greater degree in relation to the Diffuse series. This enhancement of the Principal series continues, but not in a very important manner, with the addition of more Hydrogen, whose effect, however, is very striking in the case of the Sharp series, which is increased threefold in intensity, as compared with the Diffuse.

The corresponding table (Table XX.) for Parhelium is as follows:—

TABLE XX.—General Emission in Parhelium Series.

Series.	λ.	Pure Helium.	Low pressure.	Helium with trace of H_2.	$He + H_2$.
Diffuse	6678	10	10	10	10
Sharp	5047	1·73	absent	1·49	3·98
Principal	5015	19·8	45·9	12·0	20·6

The enhancement of the Sharp series found in the case of Helium, under low pressure, may occur here also even to a somewhat greater extent, without appearing on the plate, and the effect cannot be tested. But the most significant feature is undoubtedly the behaviour of the Principal series characterised by λ5015, which is greatly enhanced in relation to the Diffuse series, in complete contrast to the corresponding effect in Helium.

The effect of a trace of Hydrogen is also directly in contrast in the two cases. In the present case it weakens the Sharp and Principal series relatively to the Diffuse.

The addition of a comparable amount of Hydrogen, however, brings the two sets of series into line, for in this case also the ultimate effect is an enhancement of the Sharp and Principal series in relation to the Diffuse. In the case of the Sharp series, the phenomenon is again very striking.

We find by a comparison which it is not thought necessary to reproduce in detail that when corresponding series of Helium and Parhelium, typified by their first members, are compared, the following conclusions may be drawn :—

The addition of Hydrogen to Helium makes only small differences in the relative radiation in any corresponding pair of lines—one a single line (Parhelium) and the other a doublet (Helium). But low pressure gives an enormous relative strengthening of the Principal series of Parhelium with respect to that of Helium. The actual ratio of relative enhancement in our experiments is about 9·0. This is, of course, one aspect of the well known character of $\lambda 5015$ as a low pressure line.

(XII.) *Discussion and Summary.*

In discussing the results obtained, it may at once be stated that the phenomena which appear to be most important are those relating to the relative intensities of lines at different distances from the cathode, for in this case we are able to define in a general way at least some of the conditions of excitation accompanying these changes. In the experiments with mixtures of Hydrogen and Helium, and at very low pressure, the observed phenomena are quite as definite, but their discussion must necessarily be more of a descriptive than of a rational nature, for the latter conditions give rise to changes in the mode of excitation which in the present state of our knowledge seem to defy any precise specification.

With regard to the changes at different distances from the cathode, it may be stated that the electric field and the average velocity of the electrons decrease with the distance from the cathode, but there is no doubt that we are at every point dealing with a very heterogeneous excitation, and although we may speak of the average velocity, we have no information as to the distribution of velocity of the electrons. Perhaps the most striking phenomenon observed relates to the difference in behaviour between the series of Helium and Parhelium, for, in the former, lines belonging to a series maintain a practically constant intensity ratio at every point, whilst in the latter, the relative intensity of any two lines of the same series varies with the distance from the cathode. In a more general summary the seat of maximum emission in Helium is the same for lines of the same series, and is peculiar to that series, whilst in Parhelium its position is affected by the term-number of the line in the series.

In the qualitative result shown in fig. 3, we see that the Band spectrum is restricted to very narrow limits as regards the conditions of excitation. The quantitative results enable us to define in a similar way the range of conditions through which the different series are most strongly developed.

The phenomena here are very definite. In the case of lines belonging to Principal series the seat of maximum emission is closer to the cathode, and falls away with increasing distance from this point more rapidly than in the case of lines belonging to associated series. The Diffuse series appear to preserve the most uniform intensity over a wide range of conditions.

Whilst it is impossible to discuss these phenomena rationally, their importance in any comprehensive theory of the origin of spectra is evident. The "dark space" is a region in which the integrated effect of all the radiations is small, and the end of the dark space in the same way is a point at which this integrated effect suffers an abrupt change, but it is evident that the true "dark space" is different for different radiations, and there appears to be another point, which in our experiments was about 5 mm. from the cathode, at which another change occurs in certain lines, whilst others do not appear to be affected; but further investigation of this phenomenon is required.

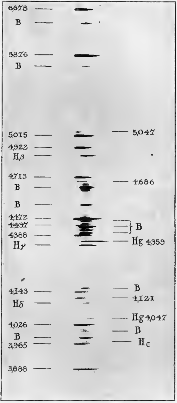
Turning now to the radiation, when the pressure in the discharge tube is very low, we find an entirely different phenomenon. Instead of a *progressive* transfer of energy in the series, there is a *selective* transfer peculiar to certain lines. In particular the lines $\lambda\lambda 4388$, 4472 and 5015 are relatively enhanced under these conditions, whilst $\lambda 3888$ is reduced. Of these lines $\lambda 4388$ and $\lambda 4472$ are especially prominent in the spectra of nebulæ, but the simultaneous enhancement of $\lambda 5015$, which is not found in nebulæ, shows that we have not isolated the conditions for reproducing the intensity relations found in the celestial spectrum, which would, however, be very closely represented by a super-position of the results at low pressure, and those found in a previous investigation when the tube was excited by a highly condensed discharge. No explanation can be offered as to the precise manner in which the excitation is altered at low pressures.

As regards the behaviour of mixtures of Helium and Hydrogen the results have not quite the same quantitative significance, in the sense that there must be small differences in the pressure of the gas in different tubes.

Taking account of this and other sources of error there are still changes which appear to be peculiar to the conditions obtaining in the mixed gases. In mixtures of Hydrogen and Helium, where the partial pressure of each gas is of the same order of magnitude, there is in general a transfer of energy in the spectra of both gases to the lines of higher term-number, in comparison with the distribution of intensity in the spectrum of Helium which was so pure that the Hydrogen spectrum could not be seen. On the other hand, in the presence of what we have called a trace of Hydrogen, the Helium lines are affected in the opposite sense; that is to say, there is a transfer of energy to the members of lower term-number. It is remarkable

that the addition of a trace of Hydrogen affects both the Diffuse and the Sharp series to a comparable extent, whilst the inverse effect produced, by a larger quantity of the lighter gas, affects the Diffuse series to a much greater extent than the Sharp series.

Finally, we may refer again to the qualitative results, which show that the seat of maximum emission is widely different for lines of Helium, Hydrogen and Mercury, and can be very strikingly seen in spite of the heterogeneous nature of the excitation in our tubes. An explanation of the apparent distribution of the elements in celestial bodies upon such a basis might be worthy of consideration, but the experimental evidence seems hardly sufficient to justify such an extrapolation.


6,678
B
5876
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4,922
Hβ
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4,472
4,437
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Hγ
4,143
Hδ
4,026
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3,965
3,888
5,047
4,686
B
Hg 4,359
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4,121
Hg 4,047
B
Hε

Fig. 3.